(54) Title: METHOD AND DEVICE FOR DETERMINING AN ANGULAR POSITION OF A REFLECTOR
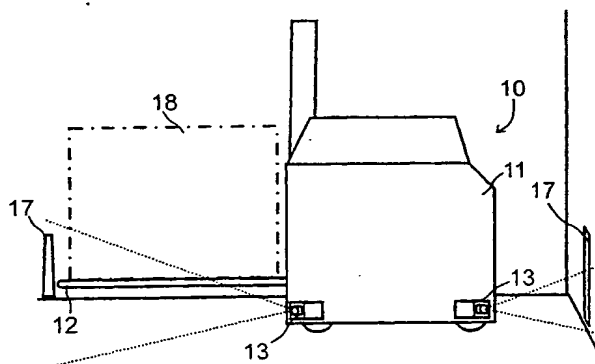
(57) Abstract: A method for determining an angular position of a reflector from a vehicle reference position in relation to an angular reference position including the step of arranging vertically extended reflectors in a working area. From the vehicle reference position vertical image slices of at least one horizontal segment of the working area are obtained, each image slice comrising a plurality of pixels and intensity values of pixels in each vertical image slice are added into a set of column sums, one position in teh set forming an angular reference point. Then the angular position of a reflector is determined as the position of a peak column sum or a subset of adjacent peak column sums in the said set in relation to the angular reference point. The invention also includes a method for determining the distance between a reflector and a vehicle reference position using reflectors with a predetermined vertical extension. The number of consecutive pixels having intensity values exceeding a predetermined intensity value is calculated and based on said number of consecutive pixels the distance is calculated. A device for determining the angular position comprises an image sensing means. An adder is provided for adding intensity values of pixels in vertical image slices into a set of column sums and computing means are provided for determining the angular position of a reflector as the position of a peak column sum or a subset of adjacent peak column sums in the said set in relation to the angular reference point.

METHOD AND DEVICE FOR DETERMINING AN ANGULAR POSITION OF A REFLECTOR

TECHNICAL FIELD

5   The invention relates to a method and a device for determining an angular position of a reflector in relation to an angular reference position including the step of arranging vertically extending reflectors in a working area.

Automated guided vehicles are used in many industrial settings, for example in the form of trucks for transport of goods in factories and ware-

10   houses.

PRIOR ART

According to a commonly used system, magnetic globs or similar devices are laid out along the transport paths of the trucks. As a result of high

15   initial costs and difficulties in later modification of the route to be followed by the trucks in such systems, new systems including light reflectors have been developed.

In some prior art systems reflectors are used with identification, that is,

20   the vehicles can determine, on the basis of the reflected signal, which unique reflector the signal is coming from. Such systems can be fast and effective, but the unique reflectors are relatively expensive. There are also limitations as regards to the distance at which the signal can be registered.

A navigation system with completely anonymous reflectors in the form

25   of reflector strips is disclosed in US-A-4811228. The reflectors lack identity but are well defined with respect to their position. The position of each reflector is stored onboard a vehicle together with relevant coordinates for the transport area. A light source onboard the vehicle sends out a concentrated laser beam that sweeps over transport area. Reflections from the reflectors

30   and other objects are registered in the vehicle and give bearings to a possible reflector.

The initial steps that are taken for defining an initial position of the vehicle are further developed in WO99/21026. Also in this case, a beam is transmitted from the vehicle over a search sector and reflected signals are

35   received onboard the vehicle. The method disclosed in WO99/21026 also

SUBSTITUTE SHEET (RULE 26)

includes steps for determining continuously the distances between reflectors and a reference point on the vehicle.

Use of a laser or other light source for producing a beam that is swept over a working area limits the design possibilities of the vehicle, because the light source should not be covered in any direction by objects onboard the vehicle. The laser device used in prior art systems normally require a complicated system of mirrors to sweep the beam around. A problem involved with the system of mirrors is that a lot of moving parts are used.

SUMMARY OF THE INVENTION

It is an object of the present invention to overcome the problems and drawbacks referred to above. According to the invention there is provided a method and a device for determining an angular position of a reflector in relation to an angular reference position. Generally, the invention can be used for determining the position of a vehicle. More specifically the invention can be used in a system for navigating an automated guided vehicle.

According to the invention an image of a working area is obtained. A simple and fast algorithm is applied to the image to substantially limit the amount of data necessary for the evaluation of the image. Intensity values of pixels in vertical image slices are added into a set of column sums. A large sum indicates the presence of a reflector in an angular position corresponding to a specific slice or a set of adjacent slices. A very precise value of the angular direction to the reflector can be determined by calculating the gravity point of the adjacent slices relating to a reflector. By using a gravity point calculation it is possible to achieve an accuracy exceeding the width of a pixel.

By using reflectors having a predetermined vertical extension it is possible also to calculate the distance from a reference position to the reflector. A method for calculating the distance includes the steps of calculating the number of consecutive pixels in a column, or vertical slice, having intensity values exceeding a predetermined threshold value. The number of such pixels corresponds, through a non-linear relation, to the vertical extension of the reflector.

3

The sums of intensity values from each vertical slice are preferably stored in a first vector. The number of elements in the first vector corresponds to the number of vertical image slices that can be obtained from an image sensor such as a CCD device. In a similar way the number of pixels

5   having an intensity value exceeding a predetermined value are gathered in a second vector. Further calculations for determining the angular position of and the distance to a reflector are then performed on the basis of the content of said first and said second vector.

According to the invention it is possible to use a conventional CCD de-

10   vice for obtaining an image of the working area where reflectors are mounted. Depending on angular working area of the CCD device it may be appropriate to mount a CCD device in each corner of a vehicle to cover a complete 360° circle around the vehicle.

Preferably, so called retro-reflectors are used. Such reflectors will re-

15   flect a large amount of incident light towards the source of light. Therefore, the light source is preferably mounted adjacent to the CCD-device.

Further features and advantages of the invention will be more apparent from the following detailed description and the accompanying claims and drawings.

20

BRIEF DESCRIPTION OF THE DRAWINGS

A further understanding of the features and advantages of the present invention may be realised with reference to the description below and to the

25   accompanying drawings, in which

Fig. 1   is a top view of an automated guided vehicle in accordance with one embodiment of the present invention,

Fig. 2   is a side elevational view of the vehicle in Fig. 1,

30   Fig. 3   is a schematic diagram showing one embodiment of a column adding section of the invention,

Fig. 4   is a diagram showing the result of adding in Fig. 3 in a segment of the obtained image,

Fig. 5   is a schematic diagram showing one embodiment of a threshold and adding section of the invention,

Fig. 6   is a diagram showing the result of adding in Fig. 5 in a segment of the obtained image, and

5   Fig. 7   is a schematic diagram showing one embodiment of a hardware in accordance with the invention

DETAILED DESCRIPTION

10   In the embodiment shown in Fig. 1 an automated guided vehicle (AGV) 10 comprises a driver unit 11 and a forklift 12. The driver unit 11 includes the electronic and hydraulic means necessary to operate the forklift 12. The driver unit 11 is rectangular and in each corner there is provided an image sensing means 13, such as a CCD camera. The view angle of the cameras

15   13 is approximately 90° as indicated by dotted lines. Each one of the cameras 13 is connected to an image processing means 14, which will be further described in connection with Figs. 3-6. The images processing means 14 is operatively connected to a computing means 15, such as a computer.

The AGV 10 is designed to operate in a working area. On walls 16 sur-

20   rounding the working area and on other suitable objects within the working area there are provided a plurality of reflectors 17. The reflectors 17 are preferably so called retro-reflectors, that is they reflect light efficiently in the direction of a light source. The reflectors preferably have less extension horizontally than vertically, as shown in Fig. 2.

25   The direction to a reflector 17 is defined in relation to a reference direction D of the vehicle. As shown in Fig. 1 an angle α is defined between the reference direction D and the direction to a reflector 17.

As shown in Fig. 2 the cameras 13 are mounted at a low vertical position. If the AGV 10 carries a load 18 as indicated by dot and dash lines a low

30   position of the cameras will allow a free view of sight below the load. It is also possible to arrange the cameras 13 at another vertical position and also more closed together, so as to achieve a more complete sight angle.

Each reflector 17 has a well defined vertical extension or height, which can be used for determining the distance between the reflector and the AGV

10, as will be further described below. Each of the cameras 13 produces a video signal, which is an input to a circuitry shown in Fig. 3 and Fig. 5. The video signal is converted in an analog-digital converter 19 to produce a digital signal for further processing. It should be noted that also digital cameras

5   could be used. In such cases the converter 19 can be left out. If a PAL video signal is used the video signal comprises 625 lines and each image is up- dated 25 times per second. In a NTSC video signal there are 525 lines which are updated 30 times per second. To obtain vertical slices of the image ob- tained by the video cameras 13 it is possible to use a frame grabber to pro-

10   duce an image containing 512x512 pixels. One line of the video signal lasts for 52 μs. There is a need for 512 points of measuring over each line. Each measuring point over one line corresponds to a pixel.

The analog-digital converter 19 is operatively connected to an adder 20, which in turn is operatively connected to a first memory means 21. The

15   intensity value in each position of the 512x512 pixels metrics is added to the corresponding intensity values of other lines in the image. Thus, a vector is formed, each element of the vector holding the sum of the intensity values of a vertical slice of the image. The full image information is condensed to a one-dimensional vector. Those positions in the one-dimensional vector that

20   correspond to a vertical slice of the image of a reflector will have a higher column sum value CS than other vertical slices. Thus, a high column sum CS indicates the presence of a reflector in a direction corresponding to the posi- tion of the element in the vector.

Fig. 4 is a diagram showing the column sum CS of a segment of the

25   image from pixel position (PP) 250 to pixel position 270. In approximately 10 pixel positions, from 253 to 263, there is a peak in the column sum. The peak indicates the presence of a reflector in an angular position corresponding to these pixel positions PP. The width of the peak illustrates that the width of a reflector exceeds the width of one pixel. This is of course related also to the

30   distance between the reflector and the camera 13. By calculating the gravity point of the peak as shown in Fig. 4 it is possible to determine the angle to the reflector at a resolution exceeding the pixel resolution. Forming the reflec- tors in the shape of a parallel trapezoid with horizontal bases, as shown in

6

Fig. 2, and thus reducing the aliasing effect inherent in discrete pixel cam-
eras, such as CCD-equipped cameras, may further increase the resolution.

The pixel position, or rather the gravity point position, of the peak as
shown in Fig. 4 corresponds to an angular position of a reflector in relation to
5   the reference direction D of the vehicle. For cameras having an angle of site
not adjoining the reference direction D an angular offset O can be used. The
circuitry of Fig. 3 will produce a first vector. On the basis of said first vector
the computing means 15 is able to calculate with high accuracy the angle
between the reference direction D of the vehicle and the reflector.

10   The circuitry of Fig. 5 also will produce a vector similar to the vector
produced by the circuitry of Fig. 3. The video signal is converted in the ana-
log-digital converter 19 and all further calculations are based on digital values
of the image intensity in each pixel. A threshold value corresponding to an
assumed intensity value from a reflector is stored in a threshold memory 22.
15   Each intensity value in digital form of a pixel is compared in a comparing
means 25 to the value stored in the threshold memory 22. If the incoming
intensity value exceeds the threshold value the content of that vector element
is incremented by one in a second adder 23. The new added value is stored
in a second memory means 24. The result of the circuitry of Fig. 5 will proc-
20   ess intensity values of a video signal to produce as a result a second vector.
Each element of the vector holds the calculated number of pixels in a vertical
column having an intensity value exceeding the threshold value stored in the
threshold memory 22.

The diagram in Fig. 6 shows the content of a segment of the vector
25   produced by the circuitry in Fig. 5. The segment of pixel positions PP from
approximately 253 to approximately 263 indicates the presence of a reflector
in the corresponding angular position. The diagram shows that number of
pixels having intensity values exceeding the threshold value is 70. The num-
ber of such pixels is indicative of the distance to the reflector, because the
30   number is indicative of the height of the reflector as seen from the camera
13.

The relationship between the number of pixels in the vector and the distance between the reflector and the camera can be expressed as in the equation below.

5

$$ph = k * a\tan\left(\frac{h/2}{x}\right)$$

where ph = height of reflector in number of pixels

h = geometric height of reflector in meters

x = distance between reflector and camera

k = optical constant

10

In one example the optical constant k was determined to be 1180. The distance was calculated with an acceptable accuracy up to approximately 25 m when using a 0,75 m reflector. It should be possible to measure larger distances by improving the light conditions during measurement.

15   Fig. 7 shows a more detailed diagram of the hardware that can be used in connection with the invention. The video signal from the cameras 13 is used as an input to the analog-digital converter 19 as described above. The video signal is also fed to a sync separator 26 for line and field synchronising signals. In the separator 26 both the line synchronising pulses and the

20   field synchronising pulses are extracted from the video signal. The synchronising signals are used in different elements of the hardware for controlling the image processing. The video signal is used also to generate a clamping signal used by analog-digital coverter 19. A synchronising means 27 is used to synchronise the cameras and other parts of the hardware. The synchronis-

25   ing means is operatively connected to the separator 26. The converter 19 converts the analog signal from the camera 13 to an eight bit digital word. At the start of each line the black level of the video signal is locked with a clamping signal.

The digital signal is fed to a comparing and adding means 28. In the

30   comparing and adding means 28 the digital value of the intensity is compared to a threshold value. If the digital intensity value is larger, that is the measured pixel is lighter than the threshold, an accumulated threshold sum is in-

8

cremented by one in that vector position. The digital signal is fed also to an
adding means 29 that adds up all the digital intensity values related to one
vertical slice of the image.

The counted number of light pixels is fed to a first FIFO memory 30
5   through a first latch 31. The FIFO memory (First In First Out) do not require
an address bus. Instead reading and writing in the memory is done by a
pulse at a clock input. A FIFO memory is an appropriate type of memory in
time critical application such as the present one.

In a corresponding way the result of the addition of intensity values in
10   the adding means 29 is fed to a second FIFO memory 32 through a second
latch 33. The first and second latches are used to retain the information so as
to allow the next unit to read the information.

An output of the first FIFO memory 30 is connected to a third latch 34
and in a similar manner an output of the second FIFO memory 32 is con-
15   nected to a fourth latch 35. Third and fourth latches are used also for a reset
during the first line of the image where no accumulated value should be
added.

Several elements of the hardware require a timer control signal. In the
embodiment shown in Fig. 7 a finite state machine circuitry 36 is used. The
20   timing can be divided into three sections. A first section relates to the actual
line been processed, a second section relates to the position on the line, and
a third section controls the generation of control signals. It should be noted
that the video signal contains also redundant image information. The relevant
information starts a few lines from the top of the image and the information at
25   each line starts at some distance from the synchronising signal.

Two specific timing situations occur. During the first line of the image
no information should be read from the first FIFO memory 30 and the second
FIFO memory 32. In these cases incoming digital image data is added to
zero and the result of the addition is stored in a FIFO memory pixel by pixel.
30   A second problem is to handle the last line of the image. The complete vector
is then fed into the first and second two port memory means 21, 24.

The computing means 15 comprises basically two elements. A first
element is a microprocessor 37, which in a practical embodiment is a Mo-

torola chip 68332. The microprocessor 37 is operatively connected to first memory means 21 and second memory means 24 for processing the content of said memories. The microprocessor 37 is also operatively connected to the image processing means 14 to receive interrupt signals and status information, for instance from the finite state machine 36.

The first memory means 21 holds a first vector, each element thereof holding the number of pixels in each column that are brighter than a threshold value. The second memory means 24 hold a second vector, each element thereof holding the sum of the intensities in each column. On the basis of said vectors the microprocessor 37 is able to calculate relevant angular positions and distances to the reflectors.

An external control register 38 is operatively connected to the microprocessor 37. The external control register 38 generates control signals to different elements of the image processing means 14. One control signal may include the threshold value used in the comparing and adding means 28.

The detection of the retro-reflective reflectors 17 is facilitated if a light source is arranged in the vicinity of each of the cameras 13. It is desired not to disturb the environment and therefore the wavelengths of the light from the light source can be within or close to the infra red area where the human eye has a low sensitivity. The light source can be a stroboscope lamp or a plurality of infrared diodes connected in series. Normally the camera is provided with an electronic shutter that is opened during a short time interval (e.g. 1/1000 s). The short opening time of the shutter makes it possible to increase the current through the diodes during that short time interval.

The infrared light source is synchronised to the camera by using the field synchronising pulse from the camera. Preferably a separated signal is obtained from the separator 26.

Due to the relatively wide field of view required, most lenses introduce a distortion of the projected image. While the evaluation algorithms described above are still valid, the device should nevertheless be calibrated to compensate for any resulting angular error.

10

CLAIMS

1. A method for determining an angular position of a reflector from a vehicle reference position in relation to an angular reference position including the step of arranging vertically extended reflectors in a working area, *characterised* by
obtaining from the vehicle reference position vertical image slices of at least one horizontal segment of the working area, each image slice comprising a plurality of pixels,
adding intensity values of pixels in each vertical image slice into a set of column sums, one position in the set forming an angular reference point, and determining the angular position of a reflector as the position of a peak column sum or a subset of adjacent peak column sums in the said set in relation to the angular reference point.

2. A method as claimed in claim 1, further including the step of calculating the gravity point of a peak formed by a peak column sum or a subset of adjacent peak column sums and determining the angular position of a reflector as the position of the gravity point.

3. A method as claimed in claim 1, wherein the reflectors have a predetermined vertical extension, further including the steps of calculating the number of consecutive pixels having intensity values exceeding a predetermined intensity value and calculating the distance from the reference position to the reflector in dependence of said number of consecutive pixels.

4. A method as claimed in claim 1, further including the steps of obtaining the vertical image slices by a discrete pixel camera and forming the reflectors as parallel trapezoids to reduce an aliasing effect occurring in such cameras.

5. A method as claimed in claim 4, further including the step of calibrating for the image distortion introduced by the camera lens.

6. A method as claimed in claim 1, wherein an image is obtained by a camera producing an analog video signal, further including the step of extracting line and field synchronising signals and intensity values from the video signal and feeding the line synchronising signal to an image processing means for

5   associating an intensity value to a specific vertical slice in dependence on a time period expired from last occurrence of the line synchronising signal.

7. A method for determining the distance between a reflector and a vehicle reference position including the step of arranging vertically extending reflec-

10   tors in a working area, *c h a r a c t e r i s e d* by
providing said reflectors with a predetermined vertical extension,
obtaining from the vehicle reference position vertical image slices of at least one horizontal segment of the working area, each image slice comprising a plurality of pixels,

15   calculating the number of consecutive pixels having intensity values exceeding a predetermined intensity value,
and calculating the distance from the reference position to the reflector in dependence of said number of consecutive pixels.

20   8. A device for determining an angular position of a vertically extending reflector arranged in a working area from a vehicle reference position in relation to an angular reference position including the step of, *c h a r a c t e r i s e d* in
that   image sensing means are provided to obtain from the vehicle refer-

25   ence position vertical image slices of at least one horizontal segment of the working area, each image slice comprising a plurality of pixels,
that   an adder is provided for adding intensity values of pixels in vertical image slices into a set of column sums, one position in the set forming an angular reference point, and

30   that   computing means are provided for determining the angular position of a reflector as the position of a peak column sum or a subset of adjacent peak column sums in the said set in relation to the angular reference point.

9. A device as claimed in claim 8, wherein said image sensing means is a
CCD camera.

5   10. An automated guided vehicle including a device for determining an angu-
lar position of a vertically extending reflector arranged in a working area from
a vehicle reference position in relation to an angular reference position
including the step of, *c h a r a c t e r i s e d* in

that   image sensing means are provided on the vehicle to obtain from the
10   vehicle reference position vertical image slices of at least one horizon-
tal segment of the working area, each image slice comprising a plural-
ity of pixels,

that   an adder is provided on the vehicle for adding intensity values of pix-
els in vertical image slices into a set of column sums, one position in
15   the set forming an angular reference point, and

that   computing means are provided on the vehicle for determining the an-
gular position of a reflector as the position of a peak column sum or a
subset of adjacent peak column sums in the said set in relation to the
angular reference point.

20

1/4

Fig. 1

Fig. 2
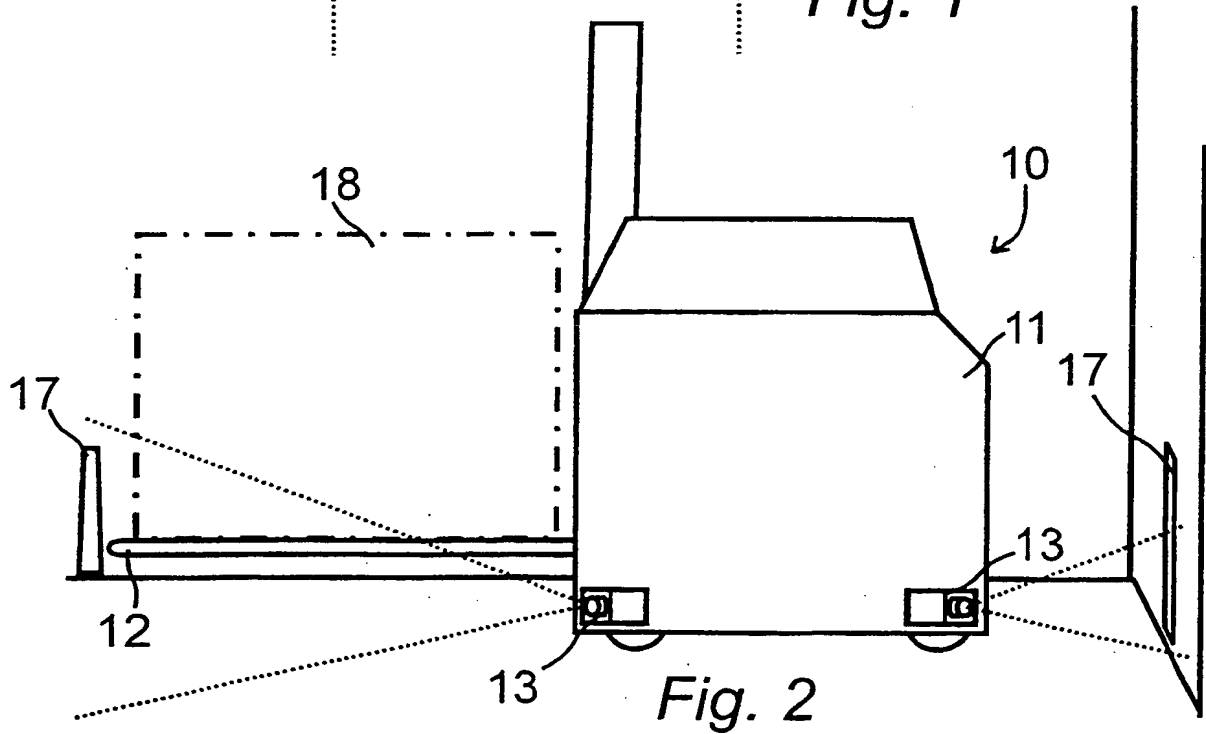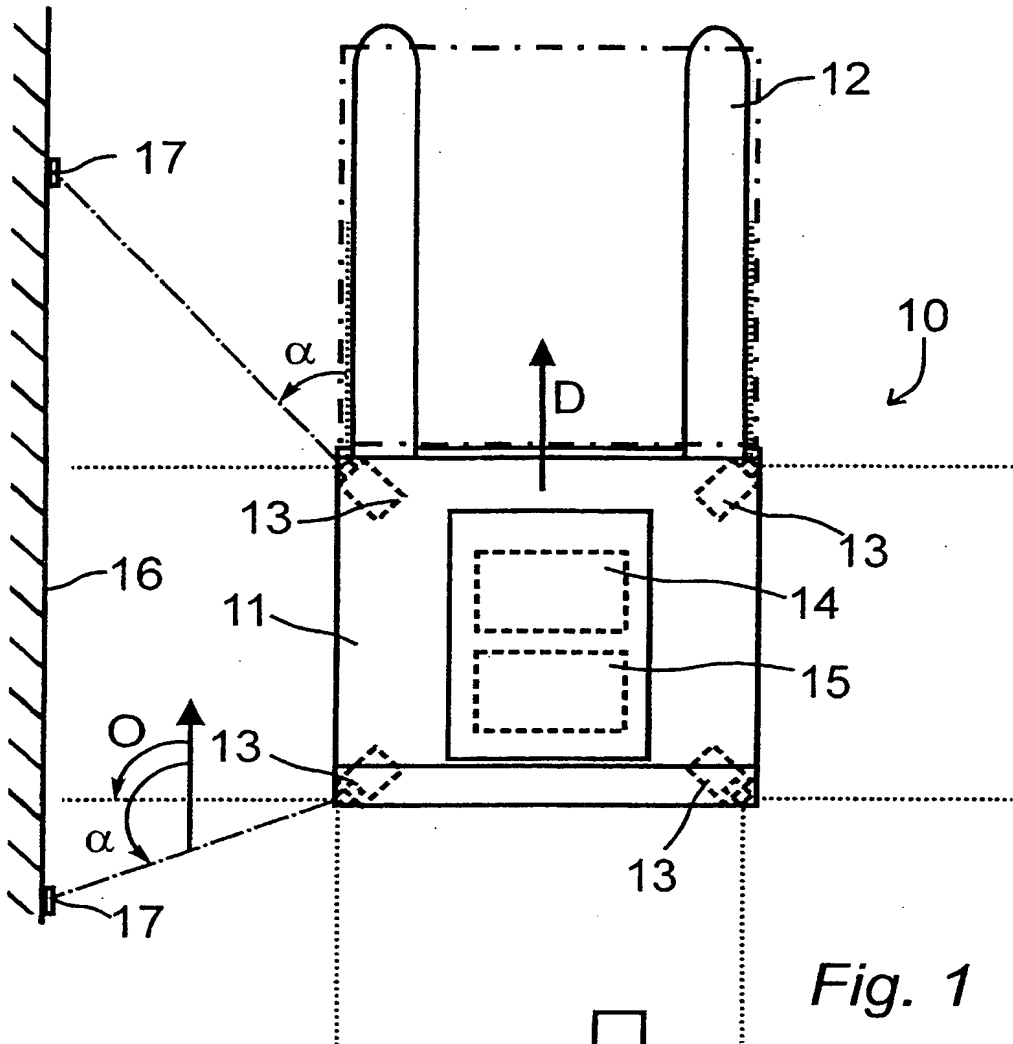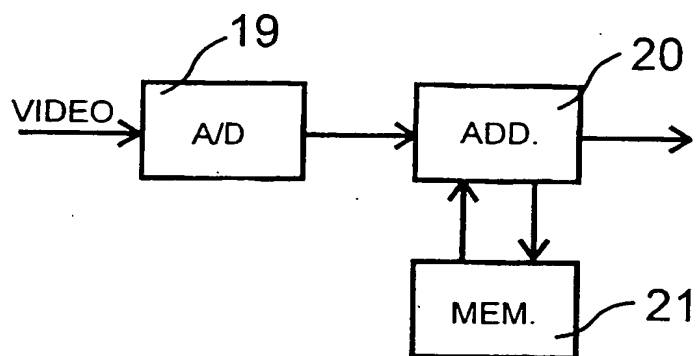
Fig. 3
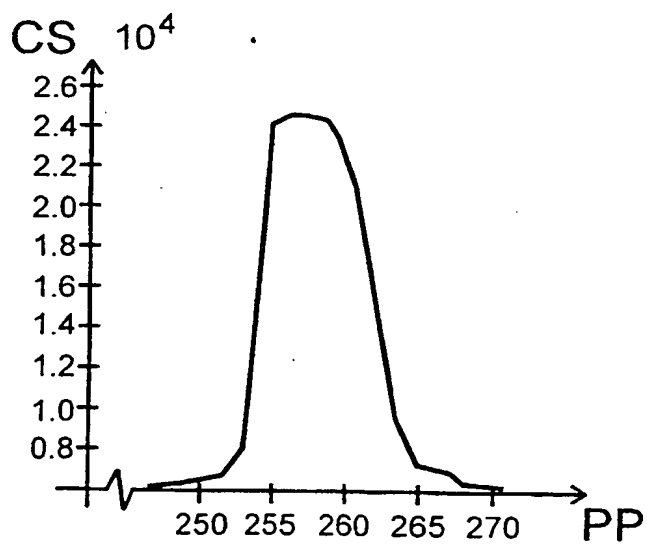
Fig. 4

3 / 4
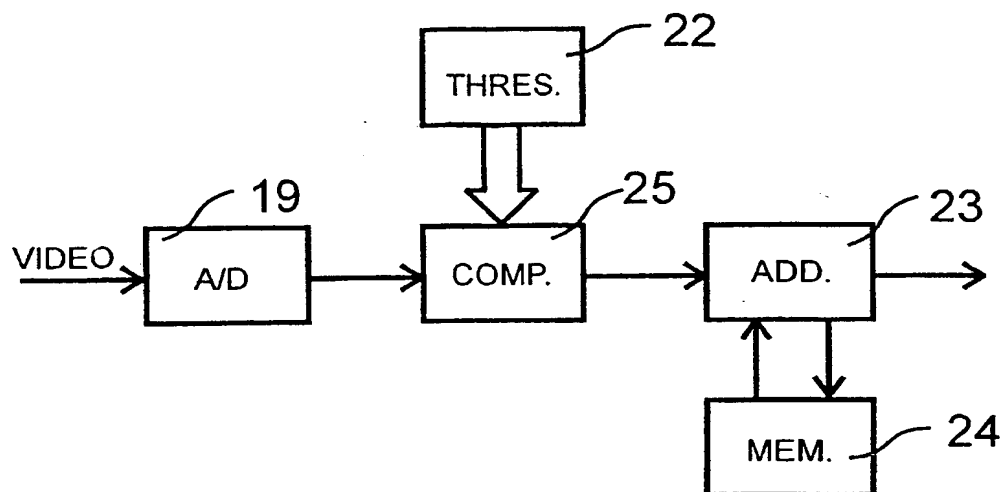
Fig. 5
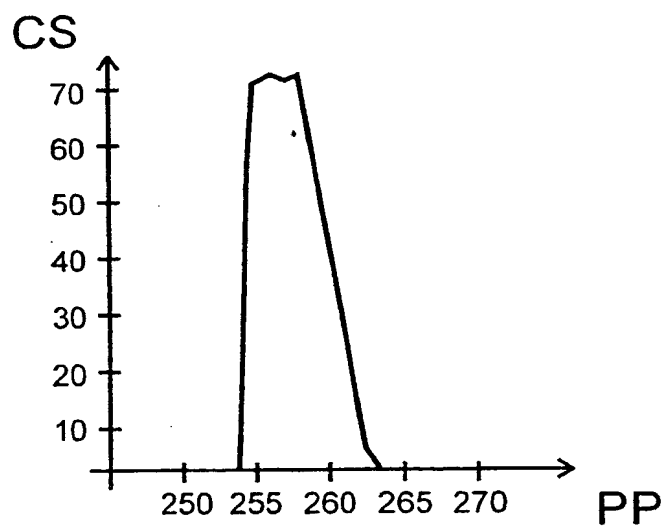
Fig. 6
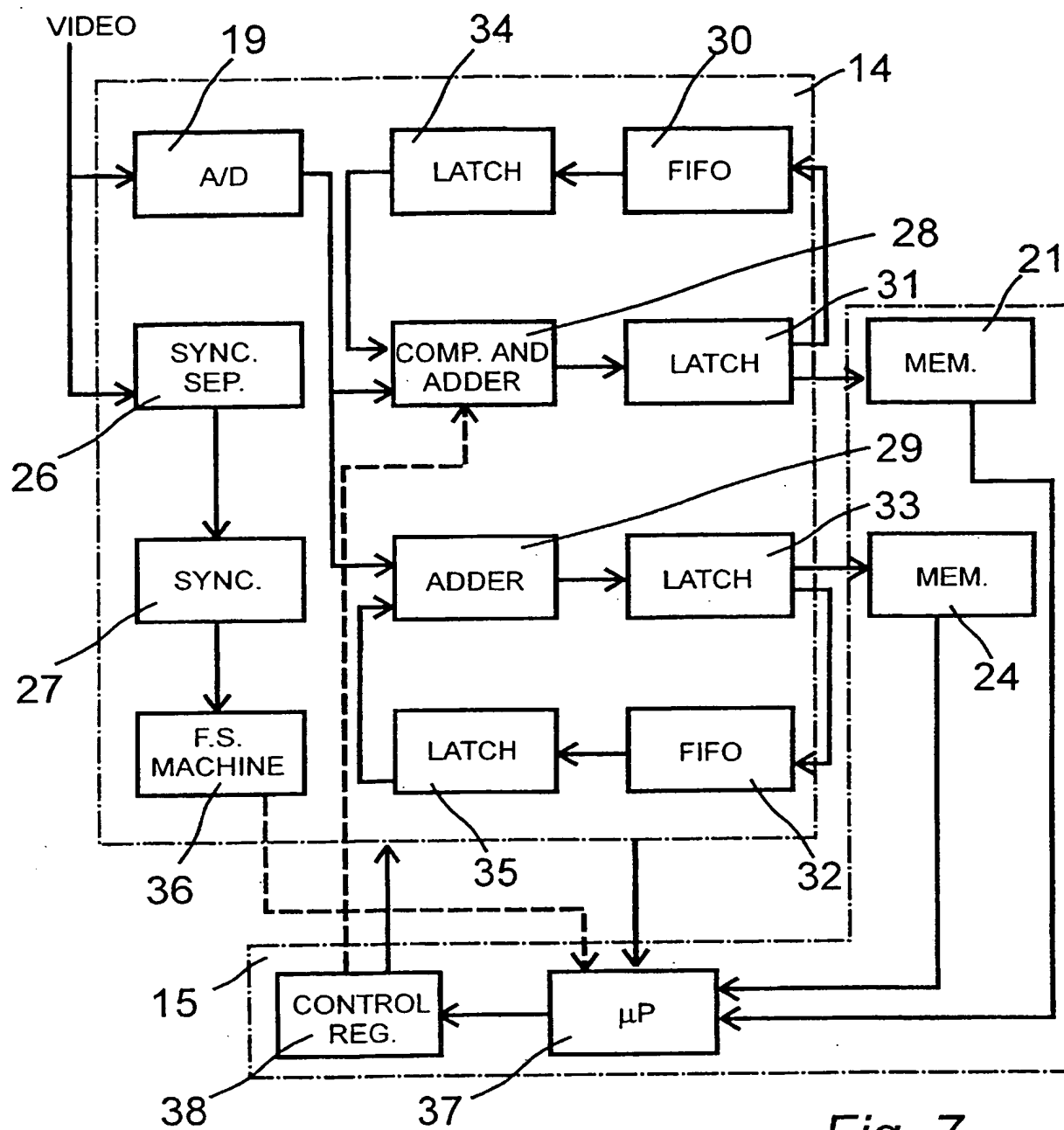
Fig. 7

INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 02/00544

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: G01S 5/16, G05D 1/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: G01S, G05D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL, WPI DATA, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5051906 A (J.M. EVANS, JR. ET AL.), 24 Sept 1991 (24.09.91), column 3, line 4 - column 5, line 59, abstract	1-10
A	PATENT ABSTRACTS OF JAPAN vol. 2000, no. 9, 16 June 2000 (2000-06-16) & JP 2000 161918 A (TSUBAKIMOTO CHAIN CO), 13 October 2000	1-10
A	US 4947094 A (R.D. DYER ET AL.), 7 August 1990 (07.08.90), column 3, line 23 - column 4, line 30, figure 3	1-10

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

Date of the actual completion of the international search	Date of mailing of the international search report
20 June 2002	2 7 -06- 2002

Name and mailing address of the ISA/	Authorized officer
Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Göran Magnusson/AE Telephone No. +46 8 782 25 00

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5051906 A	24/09/91	NONE	
US 4947094 A	07/08/90	NONE	